Research on the Temperature Control Method of an Artificial Climate Room

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Abstract: An artificial climate room plays an important role in the research of an apparatus test and indoor/outdoor environment simulation. Generally, the refrigerator is used to decrease temperature to simulate outdoor environment, while a heater is used to increase the temperature to simulate the indoor environment. It would result in large waste if the temperature control method of artificial climate room is unreasonable. It causes energy waste because it takes too much time for control process stability, which is caused by the characteristics of controlled objects such as lagging, inertia and uncertainty. Thus it is necessary to design more reasonable control methods for energy conservation. The cooling capacity for simulating outdoor temperature varies widely, so multiform controlling means is adopted, such as frequency control for the refrigerator, on/off control and auxiliary heater. While the thermal chamber which is used for simulating indoor temperature is on a long-time delay, large inertia (forced disturb is not allowed), and a new type of immune controller is designed by learning from the functions of self-adjustment, antigen memory and immunity response in biology immunity systems. By the control method, it gets a smaller overshoot and a quicker response speed in the practical process of temperature control of an artificial climate room; thus it is considered to be an optimum energy conservation method. The control method can be widely popularized and applied in an HVAC system.

Key words: artificial climate room; large lag; biology immune system; immune controller

0. INTRODUCTION

Artificial climate room plays an important role in the research of apparatus tests and indoor /outdoor environment simulation. It could be divided into the cold chamber to simulate outdoor temperature and the hot chamber to simulate the indoor temperature. Generally, refrigerator is used to decrease temperature and simulate outdoor environment, while heater is used to increase temperature and simulate indoor environment. There is great coupling between the temperature of cold chamber and that of hot chamber. It would result in a long transition process and a large energy waste if the control methods is unreasonable. The uncoupling of temperature in cold and hot chamber is the key to improve control quality. Traditional and modern methods have been summarized in the literature [2], while modern uncoupling method is less used in actual application. A more practical control method is used in the paper. Setting temperature of cold and hot chamber according to the load of artificial climate room, polymorphic control is used in cold chamber and artificial immunity control is used in hot chamber ,. Thus, the coupling and large inertia are solved preferablely, and good control index is obtained from the actual operation.

1. CHARCTERISTIC ANALYSIS of ARTIFICAL CLIMATE ROOM

The artificial climate room required by the electrical heater measurement[3] is taken as an example, and the object characters and its corresponding control scheme is analyzed in the paper. The artificial climate room is shown in Figure 1, which is made by six insulated walls and divided into cold and hot chamber. The domestic electrical heater is measured and put in hot chamber. The hot chamber temperate is required to maintain at 23℃±0.5℃ during the test period. The cold chamber is used to simulate outdoor environment temperature, and its temperature is set according to the power of measured electrical heater. The cooling capacity of cold chamber should be kept balance with the heat dissipating capacity of test electrical heater, so as to make sure hot chamber temperature constant. There are two ways for energy exchange between the cold hot chambers. One is windows of the two rooms (the heat conduction coefficient is not over 3w/(m2k)), the other is the ventilating hole between the two rooms(above windows and its air exchange quantity per hour is required to be the hot chamber volume). The forced turbulence in hot chamber is not permitted.

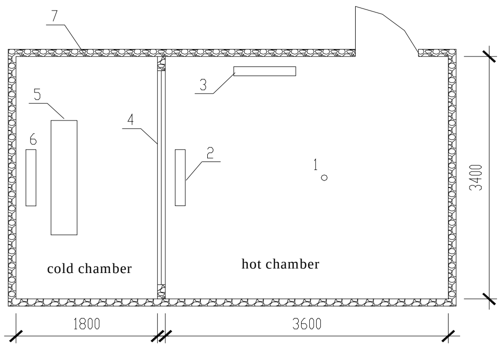

Fig.1 Ichnography of Artificial Climate Room

1-temperature control point；2-test electricity heater；
3-temperature control heater；4- glass window；
5-refrigeration plant；6- temperature control heater；7- external insulated wall

Figure 2 shows dynamic heat transfer process of artificial climate room. Cooling capacity of cold chamber and heat load of hot chamber would both result in lagging to temperature control point, and lagging caused by the latter is larger (the forced turbulence in the hot chamber is not permitted); Meanwhile they would result in inertia to temperature control point, and inertia caused by the former is larger. The tested heater in hot chamber is main disturbance in the control system. The cooling capacity varies widely （-27℃~8℃）to keep hot chamber temperature constant which is caused by large variation of heater power（300W~1500W）in hot chamber[4]; Coupling exists between hot and cold chamber temperature regulation. Above all are the characteristics of controlled object, thus control strategy should be completely considered to keep temperature stable.

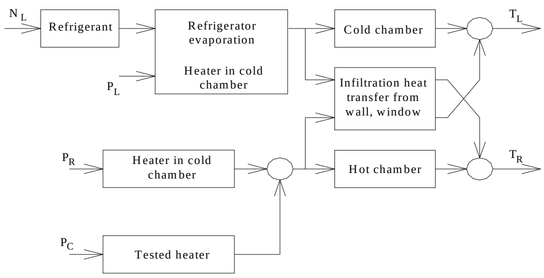

Fig.2 Block Diagram of Heat Transfer Progress in Artificial Climate Room

N_L—rotational speed of refrigerant compressor；P_L—heater power of cold room；P_R—heater power of hot room；P_C—test heater power；T_L—cold room temperature；T_R—hot room temperature；

2. IMMUNE CONTROL of HOT CHAMBER TEMPERATURE

2.1 the Immunological Regulation Principles[1]

In biological immune system the most important cells are lymphocytes mainly including B lymphocytes and T lymphocytes. Immune response is the process that immunocytes identify, activate and differentiate antigen, and it mainly depends on the interaction of T-cell subgroups including Th cells (helper T-cell) and Ts cells (suppressor T-cell).

Tab.1 The function of T cell in immune response process

Immune response process	antigen concent-ration	antibody concentr-ation	Cell T Regulati-on action
Antigen invade	large	minimum	——
Immunological primary stage	large	small	Enhance-ment
Immunological posterior stage	small	large	Inhibition
Immunological final phase	minimu m	large	——

As following is taken humour immune response as an example. Antigen is digested by APC(Antigen Presenting Cell), it firstly activates Cell Th and releases lympyokine, further activates Cell B and produces antibody. It could even slowly activate Cell Ts. Cell Th and B is repressed by the activated Cell Ts, thus stability of immune system is ensured. Table 1 displays the regulating action of Cell T in immune response process, and Figure 3 shows the humour immune response process.

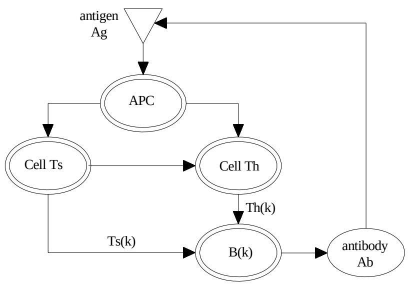

Fig.3 Response Process Diagram of Humoral Immune B cells

Th(k) — concentration of the Th cells at passage k

Ts(k) — concentration of the Ts cells at passage k

As it is showed in Table 1, the effect of T cells differs in different stages. At an immunological primary stage where the concentration of antigen is large and that of antibody is small Th cells play a major role and enhances response process; while at immunological posterior stage where the concentration of antigen is small and that of antibody is large Ts cells play a main role and response process is suppressed to ensure the stability of immune system. The immune response comes to end when concentration of antigen and antibody are both small at the time that immune system is stable. When some pathogen firstly invade the body immune response, that is primary immune response, is triggered if some T cells and B cells have high affinity to the antigens. B cells not only interact with antigen but also stimulus and suppress each other.

Some B cells would differentiate into memory B cells with a longer life period after primary immune response and they retain the antigenic characteristics to be memory cells, which is immunological memory. When the same antigen or its variants invade the organism again memory cells would be chose in advance by immune system (the choose process of memory cells), then activated, proliferate and differentiate into effector cells rapidly, and produce antibody with a higher affinity than antibody produced by initial cells. Therefore the immune response can be produced more quickly based on immune memory（that is secondary immune response） and perform highly efficient and permanent immunologic function.

2.2 Immunological P controller

Although Ts cells suppress both Th cells and B cells, the suppression mainly focuses on B cells. Figure 3 shows that B cells are not only activated by Th cells but also inhibited by Ts cells because of antigenic invade. The concentration of B cells at passage k could be expressed by function $B(k) = Th(k) - Ts(k)$, and the concentration of Th cells and Ts cells at passage k are

$Th(k) = K_1 \times \varepsilon(k); Ts(k) = K_2 \times \left\{ f\left[\Delta B(k-d)\right]\right\} \times \varepsilon(k-d)$; The concentration variation of B cells at passage (*k-d*) is

$$\Delta B(k-d) = B(k-d) - B(k-d-1).$$

Where $B(k)$ is the concentration of the B cells at passage k; $T_h(k)$ is the concentration of the Th cells at passage k; $T_S(k)$ is the concentration of the Ts cells at passage k ; $\varepsilon(k\text{-}d)$ is the concentration of the antigen at passage (*k-d*); K_1 is enhancing factor of *Th*; K_2 is inhibition factor of *Ts*; $\triangle B(k\text{-}d)$ is concentration variation of B cells at passage (*k-d*); *d* is delay time of immune response; $f[\bullet]$ is nonlinear function related to concentration variation of Cell B and it represents the immune effect due to the interaction of the antibody and antigen excreted by Cell B at the passage (*k-d*).

The mathematic representation of biology immunological P controller is

$$B(k) = K\{1 - \lambda\eta f[\Delta B(k-d)]\} \times \varepsilon(k-d) \quad (1)$$

Where η is equal to K_2/K_1 and it represents proportionality factor of interaction of T_S and T_h and $K = K_1$; λ is immune regulation effect at different stages and $\lambda = -1$ if immune enhancement, $\lambda = 1$ if immune suppression, $\lambda = 0$ if immune stabilization. Reference [4] shows how to determine variable λ、η and $f(\bullet)$.

Replacing antigen and cellular concentration in equation （1）with deviant and controlled quantity respectively, we could get the following mathematic representation for immunological P controller:

$$u(k) = K\{1 - \lambda\eta f[\Delta u(k-d)]\} \times e(k-d) \quad (2)$$

Where $u(k)$ is controlled quantity, $e(k)$ is deviant, $\triangle u(k)$ is the variation of controlled quantity, and d is delay time of system response. The theory and simulation of the immunological P controller were explained in reference [5].

2.3 Memonic Immunological P Controller

B cells would differentiate into memory cells and memorize antigenic characteristic after primary immune response. And it would response more quickly based on immune memory at secondary immune response. Therefore the mathematic representation of memonic immunological P controller is as following:

$$B(k)=K\{1-\eta f[\Delta B(k-d)]\}\times\varepsilon(k-d)+B[i] \quad (3)$$

Where *B[i]* is immunological memory cells of some specific antigen.

Immunological memory principle is introduced into equation (2) according to equation (3). Immunological memory base of secondary response is determined based on the disturbance characteristics at systemic initial operation. Subsequently immunological memory base would be remodified at every response and prepared for next response. The equation of menonic immunological P controlleris:

$$U(ki)=K\times[1-\lambda\eta f(\Delta u(k-d))]\times e(k-d)+u[i] \quad (4)$$

Where *u[i]* is immunological memory base corresponding to some special disturbance, and *U(ki)* is controlled quantity corresponding to some special disturbance.

The non basis part of immune controller would carry out immune regulation and resist external disturbance before the system came into stable state. The immune controller would memory present output after system came into stabilization and take it as immune memory base of next response.

3. MULTIFORM CONTROL of COLD CHAMBER TEMPERATURRE

Cold chamber temperature is adjusting by refrigerator and heater. Refrigeration compressor is regulating by Frequency control and run with minimum rotational speed in low load. Heater is voltage regulating by solid-state relay (SSR). The set temperature of cold chamber varies from -27℃~14℃ due to large variation of hot chamber load. Only one regulation means is difficult to achieve energy-saving control, multiform controller is designed in this paper to get the best control results. The switch point is set according to cooling demand, that is, the control means is switch based on cold chamber temperature TLZ. The cold room is regulating with PI controller if the set temperature is below $T_{LZ}-\varepsilon$, as showed in Figure 4.

Figure 4 shows the relationship between regulated quantity of cold chamber PI controller and refrigeration compressor rotational speed, heater power. Negative regulated quantity is corresponding to rotational speed regulating of refrigeration compressor and heater closing, while positive regulated quantity is corresponding to heater regulating and refrigerator compressor run in minimum rotational speed (determined by compressor surge point[4]). The cold room is regulating with ON/OFF controller if the set temperature is above $T_{LZ}-\varepsilon$, as showed in Figure 5.

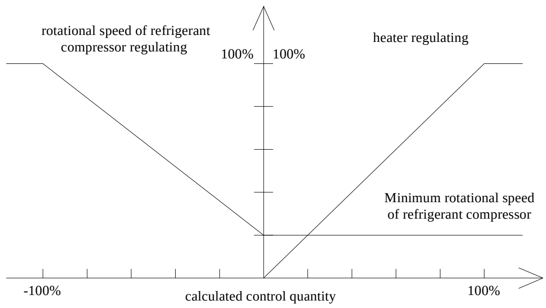

Fig.4 the Logic Diagram of Cold Chamber PI Regulation

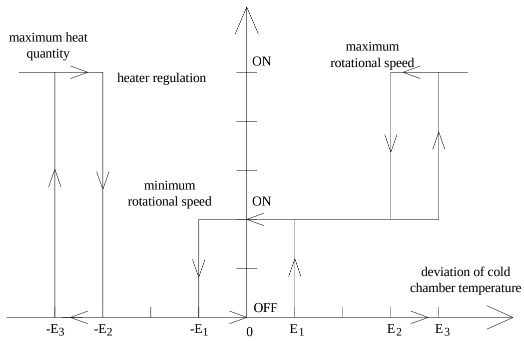

Fig.5 the Logic Diagram of Cold Chamber on/off Regulation

The set temperature of cold chamber is determined according to actual heater power. The cold chamber temperature would be reset automatically if it is not fit to the demand of hot chamber temperature.

4. LOCAL REGULATION and OPERATION

Figure 6 shows temperature control system of artificial climate room. Hot and cold chambers control systems are both run at the beginning of system operation. Hot chamber temperature is set as constant, while cold room temperature is calculated according to tested heater power. Test heater is applied automatically, and the temperature control system would close when the temperatures of hot and cold chamber are stable. Because cooling capacity of cold room is equal to heat quantity of tested heater(which is ensured by control system), the temperatures of cold and hot chamber are stable during test process.

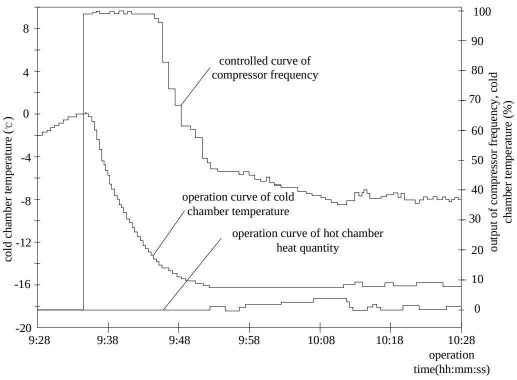

Fig.6 Temperature Control System of Artificial Climate Room

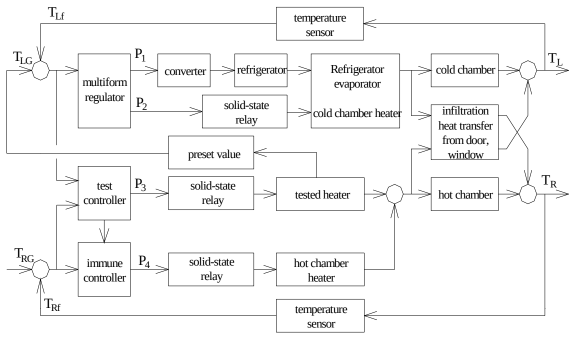

Fig.7 Transient Curve of Cold Chamber Temperature

Step response is test at the beginning of system operation. Hot chamber set temperature step changed from 20.5℃ to 23℃, and power of test heater is 1.1kW. Figure 7,8 shows recovery curve of hot and cold chamber temperature.

As following is control index of hot chamber temperature:

(1) steady-state error C: $C = 23.2-23=0.2$℃

(2)decrement ψ: $B_1 = 23.6-23=0.6$℃;

$B_2 = 23.2-23=0.2$℃;

$\psi = 1-B_1 / B_2 = 1-0.2/0.6 = 0.67$

(3) maximum deviation A: $A=B_1=0.6$℃

(4) transient time t_s : t_s =30×60=1800s

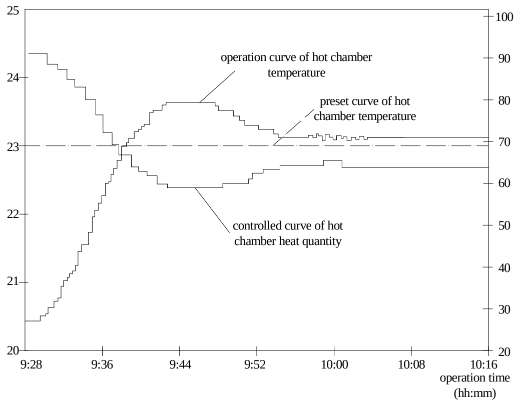

Fig.8 Transient Curve of Hot Chamber Temperature

5. CONCLUSION

The temperature-controlled objects, such as artificial climate room, are large lagging, inertia and uncertainty. It would result in a quite long time for process stability if the control method were unreasonable. According to the real characteristics of the controlled object, multiform control rules are adopted and immune controller is designed in the paper. The immune controller is learned by using for reference of biology immune control and has the functions of self-adjustment, antigen memory and immunity response. Successful practice application and optimum energy conservation control program are achieved with the control method. And the control method can be widely popularized and applied in HVAC system.

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